Transpedicle Screw Fixation of the Cervical Spine

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The use of posterior cervical spine fixation has become increasingly popular in recent years. Dissatisfaction with lateral mass fixation, especially at the cervicothoracic junction, has led spine surgeons to use cervical pedicle screw fixation for reconstruction in numerous cervical spine disorders. The biomechanical advantage of a three-column fixation device implanted to secure an unstable cervical spine has proven to be a valuable tool in the spine surgeon's armamentarium. Successful placement of a pedicle screw in the cervical spine requires a sufficient three-dimensional understanding of pedicle morphology to allow accurate identification of the ideal screw axis. Variability in cadaveric based morphometric measurements used to guide the surgeon in the placement of a pedicle screw has raised legitimate concerns as to whether transpedicle fixation can be applied without significant neurovascular complications. The emergence of computer assisted image guidance systems may be implemented in the operative protocol to improve the accurate placement of a pedicle screw. The indications for placement of a pedicle screw in the cervical spine are beginning to evolve. Only surgeons experienced in transpedicle screw fixation and surgery of the cervical spine should perform this method of instrumentation.

Today's spine surgeons have developed an interest in spinal instrumentation that uses transpedicle screws as a method of stabilization until biologic fusion occurs. Indications, screw design and placement, biomechanical advantages, and complications all have been well defined in the lumbar spine. Currently, because of the increased risk of complications, particularly neurovascular injuries, a paucity of orthopaedic and neurosurgical literature exists concerning the use of pedicle screw fixation in the cervical spine.

The goals of a fixation device used in the spine are as follows: (1) to assist in correcting or preventing additional changes in spinal alignment; (2) to enhance fusion rates; and (3) to allow early mobilization of the patient without the need for cumbersome external immobilization.

Transpedicle screw fixation allows segmental fixation of the spine for several conditions such as spondylolisthesis, tumor, instability after trauma, a multilevel lamin-
ectomy, or surgery for degenerative arthritis. This technique is useful when the posterior spinal elements (spine processes, lamina) are unsuitable for fixation by hook or wire constructs. Pedicle screw fixation methods offer three-column stability and have proven to be the most rigid posterior fixation technique.\(^3\) Because the pedicle offers the strongest point of attachment to the spine, pedicle screws provide stability by immobilizing specific spinal motion segments.

Several investigations into the possibility of transpedicle instrumentation in the cervical spine have been reported. In 1991 Panjabi et al\(^4\) published the first three-dimensional anatomic study of the human cervical vertebrae in which the capacity for the cervical pedicles to accept transpedicle fixation was shown. Biomechanical feasibility of transpedicle cervical fixation was addressed by Kotani et al\(^\text{\textsuperscript{10}}\) in 1994. In their calf cadaver model, transpedicle screw fixation offered increased stability over conventional anterior and/or posterior constructs when addressing two-column and three-column, and multilevel cervical instability. In the same year, Abumi et al\(^\text{\textsuperscript{11}}\) successfully applied transpedicle instrumentation in 13 patients with subaxial cervical trauma without complication. These three studies suggest that transpedicle stabilization in the cervical spine is not only anatomically possible, but also biomechanically superior. However, Roy-Camille\(^,\text{\textsuperscript{17}}\), the pioneer of posterior cervical spine stabilization stated that except for placement of transpedicle screws at C2, placement of transpedicle screws into the C3–C6 pedicle would be an unacceptable risk to the vertebral artery, spinal cord, and nerve roots.

Successful placement of the pedicle screw requires a thorough knowledge of cervical spine transpedicle morphometry. With such critical limits for placement, and potential catastrophic complications, concerns will be raised appropriately as to whether transpedicle fixation can be applied safely in the cervical spine.

**ANATOMIC CONSIDERATIONS**

To place transpedicle screws in the cervical spine accurately and safely, knowledge of the current available anatomic data must be analyzed. Morphometric measurements in human cadaveric studies of the critical pedicle dimensions have revealed significant variability. Because pedicle entry point, size, and orientation cannot be visualized directly from a posterior approach to the cervical spine, cadaveric data regarding pedicle anatomy are an important adjunct to preoperative radiographic studies, intraoperative fluoroscopy, and/or the use of a frameless, stereotactic computer assisted guidance system.

Panjabi et al\(^4\) quantitatively defined the three-dimensional anatomy of 12 cadaveric cervical spines. In their cadaveric series, the transverse width and sagittal height for both parameters were largest at the C2 level and smallest at the C3 level, with subsequent measurements increasing in size down to the C7 level. The cross sectional area at C2 was greater than all other levels with an unexplained 60% greater surface area on the left than the right. As a result of its inherent large area Roy-Camille\(^,\text{\textsuperscript{16,17}}\) and Smith et al\(^\text{\textsuperscript{19}}\) have reported screw fixation of C2 pedicles without neurovascular complications.\(^3\) From the fourth to the seventh cervical level, the average transverse pedicle angle of insertion was 45° at C4, 39° at C5, 29° at C6, and 33° at C7. Sagittal pedicle angulation varied from 8° caudally at C3 to 11° superiorly at C7. The transition from below to above the neutral sagittal plane occurred in this series at the C5–C6 level. Based on the analysis of Punjabi et al, the capacity for the pedicle to accommodate transpedicle fixation was shown.

An et al\(^\text{\textsuperscript{2}}\) dissected 11 cadaveric specimens at the cervicothoracic junction to topographically define the linear and angular pedicle entry point with respect to the facet joint. Because C7 is a transitional vertebra, pedicle and lateral mass screw placement are technically demanding. It is important to understand the delicate architecture of the C7
lateral mass, because placement of a screw into this structure may disrupt the facet joint or damage the nerve root. Morphometric analysis of the C7 pedicles in the series by An et al revealed a mediolateral and superoinferior outer pedicle diameter of 6.9 mm and 7.5 mm, respectively. Average mediolateral inner diameter was 5.18 mm, the pedicle length, defined as the entry point to the posterior aspect of the vertebral body, averaged 9.1 mm, and the medial angulation for the C7 pedicle averaged 34°. Based on their data, An et al recommended the pedicle entry point for the C7 pedicle was 1 mm inferior to the midportion of the facet joint with a drilling angle of 25° to 30° in the medial direction, and perpendicular to the sagittal plane.

Stanescu et al20 studied the linear and angular measurements of 16 cadaveric cervical spine pedicles from C5 to T5. From C5 to C7 there were slight increases in pedicle height, width, and length without any significant differences between adjacent levels. The angle between the perpendicular of the posterior aspect of the vertebral body and the axis of the pedicle decreased significantly from C5 (49.8°) to T1 (33.7°) with 4° to 6° between adjacent vertebral levels. Small pedicle size, with significant changes in the angle of pedicle insertion into the vertebral body, makes screw insertion at the cervicothoracic transitional region difficult. Although C7 has an increased height and width when compared with the above levels, (average width, 6.4 mm; minimum value, 4.5 mm) the proper insertion of a 3.5-mm pedicle screw remains challenging. The large standard deviation in the C7 pedicle insertion angle 40.6° ± 7.1° reveals the high degree of variability and thus the increased risk of medial or lateral perforation of the pedicle. The increase in pedicle insertion angle from C5–T5 (by 38°), with at least a 4° difference between two adjacent levels, precludes the placement of transpedicle screws at a constant angle because of the high risk of iatrogenic injury to the surrounding structures with breech of the pedicle wall.

To ensure coaxial placement of a cervical pedicle screw by topography, certain requirements must be attained. The correct entry point, as guided by the transverse and sagittal offset, must be found (Fig 1). The transverse offset determines the pedicle starting point in a mediolateral plane, as referenced from the medial aspect of the facet or the laminofacet junction. The sagittal offset determines the pedicle starting point in a cephalad to caudad plane, as referenced from the inferior facet margin of the superior vertebrae. After the correct starting point has been found, the surgeon then must direct the screw in the proper sagittal and transverse orientation.

Kramer et al also have reported detailed morphometric analysis of the cervical pedicle (nonpublished data, Kramer DL, Ludwig SC, Balderston RA, et al: Anatomic considerations related to three techniques of pedicle screw insertion. Presented at the twenty-fourth annual meeting of the Cervical Spine Research Society 1996). Precise measurements were made by two independent observers of pedicle dimensions, angulation, and offset relative to the lateral mass boundaries after the placement of Kirschner (K) wires in 140 subaxial pedicles (C3–C7) (Fig 1). The purpose was to localize the entry point and the orientation of the C3–C7 pedicles in an attempt to establish topographic guidelines for transpedicle screw placement.

Linear measurements of pedicle dimensions revealed a wide range of values with only fair correlation between observers. Average sagittal height was largest at C4 (7.72 mm) and smallest at C6 (7.15 mm). No significant interlevel difference existed. Average transverse height of the pedicle was smallest at C3 (5.38 mm), rising slightly to the largest transverse height of 6.51 mm at C7. Average pedicle length, defined as the distance from pedicle exit into the facet to entry into the posterior aspect of the vertebral body, from C3–C7 were 16.28 mm, 15.73 mm, 17.10 mm, 15.75 mm, and 14.41 mm, respectively. Average pedicle chord length, defined as the distance from the pedicle entry point to the
Fig 1. Schematic drawing of measured pedicle dimensions. PL = pedicle length; CL = cord length; TD = transverse diameter pedicle; SD = sagittal diameter pedicle; TA = transverse angulation; SA = sagittal angulation; TW = transverse width, lateral mass; SH = sagittal height, lateral mass; SO = sagittal offset, TO = transverse offset, dotted line represents the medial laminofacet junctional line.

The anterior aspect of the vertebral body, from C3–C7 was 35.53 mm, 36.11 mm, 37.20 mm, 37.40 mm, and 36.57 mm, respectively. No significant differences were detected between cervical levels for pedicle length and chord length. When comparing morphometric measurements, Panjabi et al. and Kramer et al. showed similar trends.

Angular measurements revealed similar angulation in the transverse plane (40° oriented medially) at each level. In the sagittal plane, C3 and C4 pedicles are oriented superiorly relative to the axis of the lateral mass whereas the C6 and C7 pedicles are oriented inferiorly. C5 serves as a transitional level in the sagittal plane. The mean transverse angles, oriented medially from C3–C7, were 43.97°, 44°, 41.28°, 37.32°, and 36.75°, respectively. The mean sagittal angles from C3–C7 were +8.63°, +4.67°, -1.33°, -4.02°, and -1.62°. Positive angles represented a superiorly oriented pedicle, whereas negative angles represented an inferiorly oriented pedicle. Statistically significant (p < 0.05) interlevel differences existed for the transverse angles between C3 and C7 and C4 and C6. For the sagittal angles, statistically significant differences (p < 0.05) existed between C3 and C5–C6–C7, and C4 and C5–C7.

The dorsal entry point of the pedicle on the lateral mass defined by the transverse and sagittal offset had similar mean values with wide ranges and often excellent correlation between observers. The transverse offset determines the pedicle starting point in the mediolateral plane, referenced from the medial aspect of the lateral mass. The transverse offset ratio was calculated by dividing the distance in millimeters from the laminofacet junction (medial aspect of the lateral mass) to the coaxially placed K wire, by the distance from the laminofacet junction to the lateral border of the lateral mass. The sagittal offset determines the pedicle entry site in the sagittal plane as referenced from the inferior border of a cephalad facet to the superior border of the next caudal facet. The sagittal offset ratio was calculated by dividing the distance in millimeters from the inferior border of the superior facet to the coaxially placed K wire, by the distance from the inferior border of a cephalad facet to the superior border of the next caudal facet. All ratios were expressed as a percentage.

The average transverse offset at C3–C7 was 60%, 64%, 61%, 68%, and 54%, respectively. The average sagittal offset from C3–C7 was 11%, 16%, 18%, 15%, and 17%, respectively. Neither transverse nor sagittal offset showed significant interlevel differences. Based on statistical analysis, guidelines for screw placement by cervical level were derived (Table 1).

Abumi et al. stated that because of the small depth of the pedicle in the cervical spine, the direction of the screw insertion is not so severely restricted. The cervical nerve roots run anterolaterally at 45° with respect to the transverse plane and inferiorly 10° with respect to the coronal plane. Within the neural foramina, the cervical nerve root is located at and below the disc level in the inferior half of the neural foramina. Thus,
there is only a small amount of room between the medial and inferior surface of the pedicle and the cervical nerve roots. Abumi et al, however, think that slight perforation of the pedicle by screw threads in the medial or inferior direction is safe regarding the spinal cord and nerve roots.

**BIOMECHANICAL CONSIDERATIONS**

A stable vertebral injury is defined as one in which the progression of the deformity should not occur unless a load is applied to the spine greater than that which produced the original injury. Conversely, in an unstable injury, progression of the deformity occurs under normal physiologic loads. From a biomechanical view, it is preferable to avoid surgical destruction of the residual stabilizing structures. For this reason, an optimal procedure should be a single staged anterior or posterior surgical fusion augmented with a rigid segmental fixation device. A posterior fixation device is biomechanically superior than a surgical fusion with an anterior device when injury is primarily localized to the posterior column (flexion and distraction injuries). Similarly, anterior fixation devices are more suitable than posterior devices for the stabilization of anterior injuries. The selection of fixation methods mainly depends on the evaluation of clinical instability.

Three-column fixation has not been accepted widely for use in the cervical spine. Extrapolation of the advantages over other posterior stabilization techniques may be made when analyzing the research performed in the lumbar spine. Transpedicle screw fixation systems that have been developed for the lumbar spine achieve excellent stability and strength. This in turn facilitates postoperative nursing care, allows the patients to walk immediately after surgery, decreases the need for any or minimal external support, and allows for earlier return to the patients' previous lifestyle.

The optimal spinal fixation device should control instability along the three axes of spinal motion. Moreover, its inherent multidirectional stabilizing capability preferably is obtained by isolated anterior or posterior short segmental fixation, saving as many free mobile segments as possible. The cortex of the anterior vertebral bodies in the cervical spine is not as strong as that of the posterior bony elements. Thus, even if the screws penetrate the posterior cortex of the vertebral body, anterior plate fixations do not provide as sufficient stability as posterior fixation procedures in cases of posterior injury or combined anterior and posterior injuries. Kotani et al compared the biomechanical stability of seven different cervical reconstruction methods, including transpedicle...
screw fixation under four different instability patterns. Their results showed that three-column fixation for the cervical spine using pedicle screws offered increased stability over that of conventional cervical fixation systems, particularly under torsional and extension loading. Even when the anterior and middle columns were compromised severely, the overall stability provided by transpedicle screw fixation was nearly identical to that of the combined anterior plate and posterior triple wiring for one-level fixation. The concern over large specimen to specimen differences in human cadaveric models was considered by the authors and resulted in their study being performed in a larger, more uniform calf model. It is important to realize that this study was performed using calf cervical spines, which have pedicle dimensions greater than those of human. Anatomic differences between the calf spine and the human spine is a controversial subject and as such may question the safe extrapolation of this data to that of a human model.

INDICATIONS

The indications for pedicle screw fixation of the cervical spine have not been defined clearly. Three-column fixation with transpedicle screws have increased stability and strength, and thus seem to be a useful stabilizing procedure for the reconstruction of the injured cervical spine. However, this information must be balanced against the relative dangers and technical difficulties of placing screws from C2–C7.

Transpedicle screws may be applied as a posterior stabilization device after a cervical laminectomy, in the stabilization of certain fracture patterns with loss of the lateral mass or lamina, and in the reconstruction of cervical deformity attributable to tumor, infection, or iatrogenic causes.

The authors routinely use C2, C7, and upper thoracic spine pedicle screw fixation. Clinically, this technique has been used in cases ranging from posterior fusions for anterior pseudarthroses, rheumatoid instabilities, cervical spondylotic myelopathy, tumor reconstructions, ankylosing spondylitis osteotomy reconstructions, and postlaminectomy kyphosis reconstructions.

SURGICAL TECHNIQUE

It is of paramount importance for the surgeon to review all preoperative radiographic studies to ensure that no destruction of the pedicle or vertebral body exists that may preclude the placement of a transpedicle screw. Moreover, the structural size of the pedicle and the quality of the bone may preclude the placement of a transpedicle screw. Description of transpedicle fixation in the cervical spine has been confined to the relatively large C2 pedicles. Roy-Camille described the technique and the indication for the placement of a transpedicle screw at C2 for Hangman’s fractures. For C2, Roy-Camille recommended drilling approximately 15° in the medial direction and 35° in the superior direction. The current authors combine this technique with direct palpation of the medial border of the C2 pedicle to give the surgeon the added visual and tactile sensory feedback cues that are necessary for the accurate placement of a C2 pedicle screw. The current authors use this technique to improve plate screw fixation from the occiput to C2 or C2 through the subaxial spine.

Albert et al reported on 21 patients in whom cervical pedicle screw fixation was used at C7 with or without upper thoracic pedicle screw fixation (nonpublished data, Albert TJ, Klein GR, Joffe D, Vaccaro AR: Use of cervicothoracic junction pedicle screws for reconstruction of complex cervical spine pathology. Presented at the twenty-fourth annual meeting of the Cervical Spine Research Society 1996). All pedicle screws were placed after direct palpation of the pedicle with a right angle nerve hook after a laminoforaminotomy at C6–C7. The authors
reported no neurologic complications related to pedicle screw placement and no patient was symptomatically worse after the operation. At 1-year followup no failures of fixation or complications related to pedicle fixation occurred. Albert et al concluded that pedicle screws in C7 placed with a laminoforaminotomy and palpation technique seemed to be safe and efficacious while offering excellent fixation.

The authors' preferred technique includes placing all pedicle screws after direct palpation of the pedicle with a right angle nerve hook after performing a C6–C7 laminoforaminotomy. A 2-mm burr is used to start the pedicle hole, and a drill with an automatic stop at 18 mm is used to sound the pedicle (Fig 2). A power drill is used because the pedicle is too hard for a hand drill or awl. In this region of the spine, the authors think the use of an awl or hand drill will create too much force, have too great a chance for surgical slippage, and therefore present more of a danger. All screws placed in the C7 pedicle were 3.5 mm x 20 mm. All cases should be done with intraoperative neurophysiologic monitoring. This technique is especially useful for complex reconstructions in which long fusions to the cervicothoracic junction are required (Fig 3).

Before surgery, a preoperative computerized tomography (CT) scan should be obtained to delineate the bony anatomy and the course of the vertebral artery. In most patients, the vertebral artery will be absent from the foramen transversarium of C7 (Fig 4). A study has shown that the foramen transversarium of C7 will contain the vertebral artery, vein, and associated nerve fibers in approximately 5% of patients. Therefore, CT imaging before pedicle screw placement in the seventh vertebra is necessary.

The first report of cervical pedicle screws successfully used in humans to manage subaxial traumatic injury was published in 1994 by Abumi et al. In their report, 13 patients with destabilizing cervical spine injuries were treated with transpedicle plate and screw constructs. Abumi et al also were the first to report a method for identifying the entry point of screw penetration in the posterior aspect of the lateral mass using topographic landmarks alone. The point of screw penetration at the posterior cortex of the facet was determined slightly lateral to the center of the facet and close to the posterior margin of the superior articular surface. After creating an insertion hole, the surgeon could visualize directly the entrance of the pedicle. The pedicle then could be probed,
thus enhancing visual and tactile sensory feedback cues. Laminotomies were not routinely performed to identify the medial aspect of the pedicle. In cases in which facetectomy or laminotomy had been performed for decompressive purposes, the current authors did recommend identifying the superior, medial, and inferior borders of the pedicle. Based on measurements from preoperative CT images, the intended angle of the screw was 30° to 40° medial to the midline in the transverse plane. The final angular orientation of the screws was determined using intraoperative fluoroscopy. Postoperative CT scans were performed in all patients to assess screw placement. The angle of the inserted screws ranged from 25° to 45° medial to the midline in the transverse plane. Although three cortical breaches of 52 screws placed were observed on postoperative CT scans, no neurologic or vascular complications ensued. At an average followup of 22 months, no pseudarthroses were seen.

An et al. and Fredrickson and Yuan performed human anatomic specimen investigations to determine the safest transpedicle screw technique for C7–T2. At C7, they found the pedicle entry point to be 1 mm inferior to the midportion of the facet joint, oriented 25° to 30° in the medial direction, and perpendicular to the superoinferior plane. These studies recommended that the surgeon have precise knowledge of the entrance point, size of the pedicle, and angular orientation if the decision is made to use a transpedicle screw at these levels.

Xu et al. in 1995, reported morphologic data of the C7 lateral mass and pedicle in a human cadaver model. As part of this investigation, the axial projection of the C7 pedicle on the posterior aspect of the lateral mass.

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**Fig 3.** (A) Anteroposterior and (B) lateral radiographs of a C2–C7 anteroposterior fusion fixed with a C7 pedicle screw at the inferior end of the construct for kyphosis reconstruction after laminectomy.
was described in an attempt to provide guidelines to place pedicle screws safely at this level alone. This information has been used successfully in efforts to provide improved fixation of lateral mass plates at the cervicothoracic junction. In general, given the poor quality of the C7 lateral mass, the authors prefer a pedicle screw at this level.

Given the variability of the pedicle topography and the authors' reluctance to rely on blinded insertion of pedicle screws, an investigation was done to determine the safest and most efficacious way to place cervical pedicle screws. Kramer and Ludwig et al instrumented 12 human anatomic specimen cervical spines with 3.5-mm screws placed in the pedicles from C3 through C7 according to one of three techniques (nonpublished data, Kramer DL, Ludwig SC, Balderston RA, et al: Anatomic considerations related to three techniques of pedicle screw insertion. Presented at the twenty-fourth annual meeting of the Cervical Spine Research Society 1996). In Group I, screws were placed using the topographic guidelines derived in the first part of the study. In Group II, the same guidelines were used after laminoforaminotomies were performed to provide supplemental visual and tactile cues regarding the orientation of the pedicle. In Group III, screws were placed using a computer-assisted image guided surgical system, the Stealth Station (Sofamor Danek, Memphis, TN), which applies stereotactic principles to preoperative CT data allowing transformation of real-time data from the operative site into the virtual world data of the CT image. Cortical integrity then was assessed by obtaining postoperative CT scans (1-mm cuts) of each specimen. A cortical breach was considered critical if the screw encroached on any vital structure such as the vertebral artery, cervical nerve root, or spinal cord. These findings then were confirmed by dissecting circumferentially around each pedicle.

In Group I, using topographic data alone, only 12.5% of screws were placed entirely within the pedicle, 21.9% had a noncritical breach, and 65.5% had a critical breach. In Group II, using laminoforaminotomy, pedicle palpation, and topography, 45% were within the pedicle, 15.4% had a noncritical breach, and 39.6% had a critical breach. There were no critical breaches at the C7 level. In Group III, using computer-assisted image guided surgery, 76% were entirely within the pedicle, 83.4% had a noncritical breach, and 16.6% had a critical breach. There were no critical breaches at the C6 or
C7 levels. When a critical breach was encountered, regardless of which surgical technique was used, the vertebral artery was likely to be injured in 73.9%, whereas the exiting nerve root was likely to be injured in 41.5%.

Although a statistical analysis of morphometric data obtained from the cervical spine can provide guidelines for transpedicle screw placement based on topographic landmarks, sufficient variation exists to preclude safe instrumentation without additional anatomic data. Furthermore, insufficient correlation between different surgeons’ assessments of surface landmarks attests to the inadequacy of screw insertion techniques in the cervical spine based on such specific guidelines. Although laminoforaminotomy palpation does improve visual and tactile access to the cervical pedicle, this technique did have a significant likelihood of injuring vital structures above the C7 vertebral body. Finally, frameless stereotactic systems enhance accuracy and additionally improve the safety of transpedicle screw placement, most notably at C6 and C7.

IMAGE GUIDED INSERTION OF TRANSPEDICLE SCREWS

Three-dimensional reconstruction of tomographic images have shown that the greatest width and optimal trajectory measured from a single image may not correspond to the true optimal screw axis through the pedicle. Clinically, this was confirmed by failure rates in screw placement and subsequent complications that have been reported. Because of the significant variability in morphometric dimensions reported in the literature, interest has emerged in image guided insertion of pedicle screws. Nolte et al\textsuperscript{13} presented their technique for spinal surgery that combines preoperative tomographic imaging with the principles of stereotaxis. Stereotaxis is used to locate positions within a body without direct access to its interior. An important principle in stereotactic surgery is to trace an in vivo anatomic point that was pre-defined by the preoperative radiographic image. A computer assisted surgical system then correlates the intraoperative in vivo and preoperative radiographic studies to guide the surgeon in the placement of a transpedicle screw.

For a stereotactic tracking system to be helpful in the placement of a transpedicle screw, the device should meet certain stringent criteria. The instrumentation should be easy to use. The computer should not interfere with and require only slight modifications of standard surgical procedures and principles. The computer should provide sufficient accuracy, over more conventional means, in directing the surgeon to the correct entry point, trajectory, and depth of insertion. The system should be fast enough to allow real time instrument control and visualization. Because there is no need for intraoperative fluoroscopy, and the process of landmark identification is guided by the computer, the total surgical time should not be effected significantly.

As mentioned in the previous section, the present authors used a computer assisted surgical system, the Stealth Station, to assess the applicability, functionality, and accuracy of this spinal fixation technique in human anatomic specimen cervical spines. Preoperative CT scans were obtained for all specimens with a 1–mm slice thickness. A computer model then was built based on the preoperative scans. An ideal axis for pedicle screw insertion was planned preoperatively by defining the appropriate entry and target points on the computerized model. The coordinates of three to six additional anatomic landmarks also were captured for later use in an intraoperative paired point matching procedure. During the intraoperative session, registration of the predetermined anatomic landmarks was performed by localizing and digitizing the landmarks with a space pointer. Once this matching process is completed, the real world of the operating room is able to communicate in real time with the
virtual world data of the computer based model. Next, under computerized image guidance, the screw hole was drilled along the chosen trajectory. A standard drill can be mounted with a housing containing light emitting diodes, which relay drill tip position and orientation to an optic reader. This allows for the transformation of the real world data from the operative field into the virtual world data of the computer image. During the actual drilling, computerized guidance functions assist the surgeon in matching the chosen trajectory. These guidance functions include a display of colored lines representing the preoperatively planned trajectory relative to the real time trajectory of the drill bit in the sagittal, transverse, and coronal planes. Once the pilot hole has been prepared, 3.5 mm x 12 mm screws were inserted without additional visualization. The presented technique provided a safe and accurate basis for transpedicle screw placement in the cervical spine, especially at the C6 and C7 levels.

COMPLICATIONS

Intraoperative and postoperative complications associated with the technique of cervical spine pedicle screw fixation can be derived from the thoracolumbar pedicle screw literature. This is because of the recent emergence and paucity of literature concerning the placement of transpedicle screws in the cervical spine. According to Esses et al, in their analysis of 617 surgical cases in which pedicle screw implants were used, the most common intraoperative problem was unrecognized screw misplacement (5.2%). Fracturing of the pedicle during screw insertion and iatrogenic cerebrospinal fluid leak occurred in 4.2% of cases. The postoperative deep infection was 4.2%. Transient neuropraxia occurred in 2.4% of cases, and permanent nerve root injury occurred in 2.3% of cases. Screw breakage occurred in 2.9%. The overall rate of complication was 27.4%. The intraoperative complication rate was 9.6%, and the postoperative complication rate was 17.8%. Esses et al also showed that the complication rate was significantly higher in patients with previous spine surgery versus those undergoing spine surgery for the first time (44.7% versus 17.8%, \( p < 0.001 \)).

Transpedicle cervical spine screw insertion is associated with obvious risks to major neurovascular structures, including the spinal cord, nerve root, and vertebral arteries. In the current authors cadaveric study, they were able to show that regardless of which surgical technique was used, the vertebral artery is the structure most likely to be injured followed by the exiting nerve root. In two clinical series of pedicle screw fixation for degenerative or traumatic lesions of the middle and lower cervical spine, neither Abumi et al nor Albert et al reported any neurovascular complications with the placement of pedicle screws (nonpublished data, Albert TJ, Klein GR, Joffe D, Vaccaro AR: Use of cervicothoracic junction pedicle screws for reconstruction of complex cervical spine pathology. Presented at the twenty-fourth annual meeting of the Cervical Spine Research Society 1996). In these series no pseudarthroses were reported at a 12- to 22-month followup.

With all the advantages that the pedicle screw offers, concerns over surgical complications, safety, and efficacy have surfaced. Currently, these concerns only have been reported with the placement of the screw in the lumbar spine. Unfortunately, it is unknown whether this data can be extrapolated to the cervical spine. As the indications and technique for the placement of pedicle screws in the cervical spine become more well defined, additional complications will emerge.

Successful placement of a pedicle screw in the cervical spine requires sufficient three-dimensional understanding of morphologic features of pedicles to allow accurate identification of the ideal screw axis. At present, cadaveric based morphometric measurements used to guide the surgeon in the placement of a pedicle screw have revealed signif-
ificant variability, and thus have raised legitimate concerns as to whether transpedicle fixation can be applied safely. The indications for placement of pedicle screws in the cervical spine are beginning to evolve. A three-column fixation device implanted to secure an unstable cervical spine has proven to be a valuable tool in the spine surgeon's armamentarium because of its biomechanical advantage. Emergence of a computer assisted image guidance system may be implemented in the operative protocol for accurate placement of a pedicle screw because of the unforgiving anatomic boundaries of the cervical spine. Presently, the authors think that only surgeons experienced in transpedicle screw fixation and surgery of the cervical spine should perform this type of instrumentation.

References